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PROBING INFRARED SOURCES BY COMPUTER MODELING

FINAL TECHNICAL REPORT

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SUMMARY

The general objectives of the funded research are as follows: (1) to construct detailed models for various infrared sources and parameterize the observed characteristics in terms of their physical properties, (2) to identify diagnostic tools and develop reliable semi-empirical relationships to facilitate the rapid interpretation of observations, and (3) to model grain formation phenomena in expanding envelopes around evolved stars. In all of these, emphasis is on studying the observational consequences of the models. Below is a list of projects completed during the tenure of this grant. A brief description is given for projects for which results are not yet published. Those with publications are given as titles only.

1. *Detailed Modeling of Infrared Sources (e.g., R. Coronae Borealis, IRC+10216)*

2. *Evaluation of Existing Methods of Analysis in Infrared Astronomy*

3. *Grain Formation in Stellar Outflows (e.g., carbon stars)*

4. *Extinction and Infrared Emission of Fractal Dust Grains*

We have studied the effects of fractal dust grains on the spectrum of infrared sources and have identified fractal dimension (p) as a shape parameter for characterizing the optical and thermal properties of dust grains. Grains with a higher p attain a higher temperature. Furthermore, grains having the same fractal dimension show almost no difference in their absorption cross sections and energy spectrum, implying that the overall grain shape plays a minor role in the thermal properties. We have also studied the detailed effects of fractal grains on the shapes and intensity ratio of the 10 and 20 μm silicate features in the emergent flux spectrum.

5. *Transient Heating of Very Small Grains*

We have studied the effects of transient heating of very small grains on the flux spectrum of infrared sources. Using self-consistent radiative transfer models (for both classical and transiently heated particles), we have modeled the IRAS surface brightness observations of the Chamaeleon diffuse cloud. We found that good fit could be obtained using either PAHs or HACs. Their differences could be observed through photometry in the K and M bands. We have also modeled the dark globule B335 which shows a mid-infrared excess. We have compared the results of two models: an internally heated one with only conventional large grains, and an externally heated one with both large and very small grains. Both models can reproduce the observed flux spectrum, implying that mid-infrared excess in dark globules does not uniquely imply the presence of an internal heat source.

WORK PARTIALLY SUPPORTED BY NASA GRANT NAGW-2817

A. Papers Published/In Press

1. Leung, C. M., "Probing Infrared Sources by Computer Modeling.", in *Astronomy in New York State*, ed. A. G. D. Philip, L. Davis Press, p. 105 (1992).
2. Leung, C. M., "Phenomenological Modeling of Infrared Sources: Recent Advances.", in *Astronomical Infrared Spectroscopy: Future Observational Directions*, ed. S. Kwok, ASP Conference Series, No. 41, p.189 (1993).
3. Doty, S. D. and Leung, C. M., "A Critical Evaluation of Semi-Analytic Methods in the Study of Centrally Heated, Unresolved Infrared Sources.", *Astrophysical Journal*, **424**, 729 (1994).
4. Egan, M. P. and Leung, C. M., "Grain Formation Around Carbon Stars: I. Stationary Outflow Models.", *Astrophysical Journal*, **444**, 251 (1995).
5. Leung, C. M., "Theoretical Studies of Dust in the Galactic Environment: Some Recent Advances.", in *The Physics of the Interstellar Medium and Intergalactic Medium*, ed. A. Ferrara, C. Heiles, C. F. McKee, and P. Shapiro, ASP Conference Series, Vol. 80, p. 148 (1995).
6. Leung, C. M., "Modeling Astrophysical Phenomena Involving Dust.", in *The Cosmic Dust Connection*, ed. J. M. Greenberg, NATO ASI Series, Kluwer Academic Publishers, to appear (1996).
7. Nagendra, K. N. and Leung, C. M., "Models of Highly Extended Dust Shells Around R Coronae Borealis.", *Monthly Notices of the Royal Astronomical Society*, to appear (1996).

B. Papers Submitted/In Preparation

1. Doty, S. D. and Leung, C. M., "Detailed Chemical Modeling of IRC+10216: Effects of Photo- and Grain Surface Chemistry.", submitted to the *Astrophysical Journal*.
2. Fogel, M. E. and Leung, C. M., "Modeling Extinction and Infrared Emission from Fractal Dust Grains.", in preparation, to be submitted to the *Astrophysical Journal*.
3. Egan, M. P. and Leung, C. M., "Grain Formation Around Carbon Stars: II. Time Dependent Models.", in preparation, to be submitted to the *Astrophysical Journal*.
4. Doty, S. D., Lis, D. C., and Leung, C. M., "Radiation Transport in the Presence of Transiently Heated Dust Grains.", in preparation, to be submitted to the *Astrophysical Journal*.

C. Contributed Papers (Oral and Poster) Presented in Conferences

1. Egan, M. P. and Leung, C. M., "Grain Formation in Stellar Outflows: Coagulation Effects", *New York State Astronomy*, ed. A. G. D. Philip (Schenectady, New York: L. Davis Press), p. 147 (1992).
2. Fogel, M. E. and Leung, C. M., "Modeling the Infrared Spectra of Fractal Dust Grains.", *New York State Astronomy*, ed. A. G. D. Philip (Schenectady, New York: L. Davis Press), p. 149 (1992).

3. Egan, M. P. and Leung, C. M., "Modeling Grain Formation in Stellar Outflows.", *Astronomical Infrared Spectroscopy: Future Observational Directions*, ed. S. Kwok (San Francisco: Astron. Soc. of the Pacific), p. 221 (1993).
4. Egan, M. P., Leung, C. M., and Coffin, D. J., "Time Dependent Models of Circumstellar Dust Formation.", *Bull. Amer. Astron. Soc.*, **25**, 1313 (1993).
5. Fogel, M. E. and Leung, C. M., "Fractal Grains and the Interstellar Extinction Curve.", *Bull. Amer. Astron. Soc.*, **25**, 1434 (1993).
6. Doty, S. D., Leung, C. M., and Lis, D. C., "Modeling Transient Heating in the Chamaeleon Diffuse Cloud: VSGs, PAHs or HACs?", *The First Symposium on the Infrared Cirrus and Diffuse Interstellar Clouds*, ed. R. M. Cutri and W. B. Latter (San Francisco: Astron. Soc. of the Pacific), p. 408 (1994).
7. Doty, S. D., Leung, C. M., and Lis, D. C., "Modeling the Infrared Spectra of Dark Globules: Effect of Transiently Heated Small Grains.", *Bull. Amer. Astron. Soc.*, **26**, 883 (1994).
8. Leung, C. M., "Challenges in Modeling Astrophysical Phenomena Involving Radiative, Reactive, and Multiphase Flows.", *Bull. Amer. Astron. Soc.*, **26**, 945 (1994).
9. Fogel, M. E. and Leung, C. M., "Extinction and Infrared Emission from Fractal Dust Grains.", *The Cosmic Dust Connection*, ed. J. M. Greenberg, NATO ASI Series (Dordrecht: Kluwer Academic Publishers), p. xxx (1996).
10. Joiner, D. A. and Leung, C. M., "Using a PC to Model Radiation Transport in a Dusty Medium.", *Polarimetry of the Interstellar Medium*, ed. W. G. Roberge and D. C. B. Whittet (San Francisco: Astron. Soc. of the Pacific), p. xxx (1996)

D. Doctoral Dissertations Completed

1. Egan, M. P. "Dust Formation in Stellar Outflows: A Time Dependent Model.", Ph. D. Thesis, Rensselaer Polytechnic Institute, December 1993.
2. Doty, S. D. "Modeling the Outer Regions of Evolved, Carbon-Rich Circumstellar Envelopes: Application to IRC+10216.", Ph. D. Thesis, Rensselaer Polytechnic Institute, April 1995.

E. Invited Lectures

About a dozen invited lectures were given as seminars, colloquia, and review talks at universities, research institutions, conferences, AAS meeting, and workshops.